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AN INNOVATIVE APPROACH FOR ASSESSING THE ERGONOMIC RISKS OF LIFTING TASKS USING A VIDEO MOTION CAPTURE SYSTEM

by

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March 2006

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ABSTRACT

Low back pain (LBP) and work-related musculoskeletal disorders (WMSDs) can lead to employee absenteeism, sick leave, and permanent disability. Over the years, much work has been done in examining physical exposure to ergonomic risks. The current research presents a new approach for assessing WMSD risk during lifting related tasks that combines traditional observational methods with video recording methods. One particular application area, the Future Combat System Medical Evacuation Vehicle (FCS MV-E) mockup, was chosen to illustrate the use of a two-dimensional motion capture system. Combat medics (MOS 91W) who perform casualty evacuation under stressful battlefield conditions may be at risk for musculoskeletal injuries, which would reduce their ability to perform their job. The objective of this study is to demonstrate the use of video motion technology for posture analysis of team lifting and loading tasks. The results contribute to a determination of whether combat medics are at risk for WMSD due to awkward postures involved in the evacuation of litter casualties. Based on lessons learned from the current study, recommendations are offered to guide further research in motion analysis of manual material handling tasks.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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EXECUTIVE SUMMARY

Biomechanical and epidemiological studies have identified the association of work-related musculoskeletal disorders (WMSDs) and low back disorder (LBD) with manual materials handling (MMH) and lifting demands. Researchers have used a variety of techniques to investigate physical exposure to WMSD risks; ranging from paper-and-pen based observational methods to self-report assessments. However, very little research has used video motion capture techniques to observe posture of MMH team tasks. A particular design in progress was chosen to demonstrate the use of this technology to evaluate potentially harmful postures.

The United States Army has developed a transformation program known as the Future Combat System (FCS) as a step towards meeting the objective of fielding a Future Force by the end of this decade. This program is a joint networked "system of systems" that uses advanced communications and technologies to integrate the soldier with "families" of manned and unmanned platforms and sensors. Among these families of vehicles is the Medical and Evacuation Vehicle (MedEvac), which has two interchangeable modules - the evacuation vehicle (MV-E) and the treatment vehicle (MV-T). Human factors research is necessary at this stage of the design process, especially with the Army's initiative towards reduced manning in future systems. It is hypothesized that combat medics (MOS 91W) who perform casualty evacuation tasks are at risk for musculoskeletal injuries. The aims of this thesis are (i) to demonstrate a novel approach for assessing musculoskeletal risk by using a motion capture system in a military environment, (ii) to identify and describe the most physically demanding tasks and task elements performed by the medical crew, (iii) to evaluate the postures that personnel employ while conducting evacuation of litter casualties, (iv) to recommend a methodology to investigate postural risk of lifting related tasks, and (v) to address ergonomic issues in team lifting, and (vi) to recommend ergonomic design interventions for the MV-E litter lift system. A

postural analysis of the litter loading process using 2-person and 3-person teams was accomplished by task simulations in the MV-E mockup. Participants were asked to load the maximum capacity for the MV-E to simulate a worst case scenario. Therefore, the two teams replicated the evacuation of four litter casualties. In addition, a medic served as a subject matter expert (SME) and facilitated the litter-bearers while performing the loading exercise. During task simulation, a video recording system was used to analyze the postures used to perform the loading task. Using a 2-D motion capture system, the loading postures were analyzed and compared with generally accepted ergonomic and biomechanical principles. Estimates of the probability of injury associated in performing the litter loading tasks were generated by measuring trunk characteristics such as trunk angles and trunk acceleration as well as workplace characteristics such as the height of the load at the origin and destination of lift.

I. INTRODUCTION

A. BACKGROUND

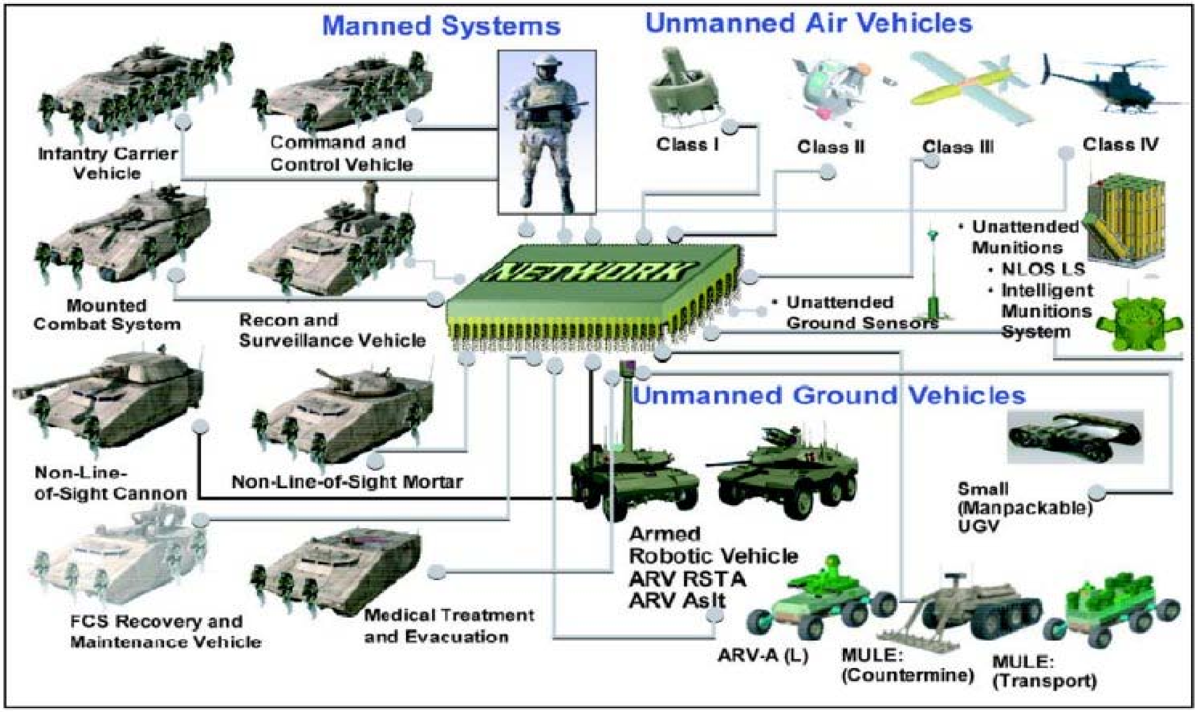
1. Medical Evacuation Vehicle

The United States Army has a vision of fielding a Future Force by the end of this decade. In order to achieve this objective, the Army has developed a transformation program known as the Future Combat Systems (FCS). This program is a joint networked "system of systems" that uses advanced communications and technologies to integrate the soldier with "families" of manned and unmanned platforms and sensors (see Figure 1). A soldier linked to these platforms and sensors will have access to data that enable levels of joint connectivity, situational awareness and understanding, and synchronized operations that were not achievable in the past. In January 2003, the U.S. Army Defense Advanced Research Projects Agency (DARPA) granted an award to Lead Systems Integrator (LSI), Boeing/SAIC to form an Integrated Design Team for the Manned Ground Vehicle portion of the FCS program. BAE Systems (formerly United Defense Limited Partnership, UDLP) and General Dynamics Land Systems, along with the LSI, together form the Integrated Design Team.

Among the family of vehicles BAE is responsible for developing and building is the Medical and Evacuation Vehicle (MedEvac). The FCS Medical Vehicle has two interchangeable mission modules- the evacuation vehicle (MV-E) and the treatment vehicle (MV-T). The MV-E is designed to enable trauma specialists, maneuvering with combat forces, to be closer to the casualty's point-of-injury and is used for casualty evacuation. It provides a means of transporting the wounded out of harm's way to a battalion aid station (BAS). The three-person crew; a vehicle commander, medical attendant, and a driver, are all medically trained staff in the military occupational specialty (MOS) 91W Healthcare Specialist. The MV-E is capable of carrying up to six ambulatory casualties, or an arrangement of three litter casualties, three ambulatory casualties, and one medic workstation. An automatic litter lift system to be installed in this vehicle is a design feature uniquely different from predecessor

vehicles. The litter lift system is used to load and unload casualties into the Medical Evacuation vehicle and has the capability to carry three litter casualties and converts to accommodate three ambulatory casualties.

Figure 1. Future Combat System (FCS) family of vehicles (From Global Security, 2005)



2. Manual Materials Handling and Work-related Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) represent a wide range of disorders to include a group of conditions that involve the nerves, tendons, muscles, and supporting structures such as intervertebral discs. MSDs can differ in severity from mild periodic symptoms to severe chronic and debilitating conditions (National Institute for Occupational Safety and Health [NIOSH], 1997). Repetitive strain injuries (RSIs), cumulative trauma disorders (CTDs), and overuse syndromes are other terms used for MSDs. Work-related musculoskeletal disorders (WMSDs) are MSDs caused or intensified by the work environment. Some examples of WMSDs are carpal tunnel syndrome, tendonitis, epicondylitis,

trigger finger, and low back pain. Certain characteristics of the work setting have been associated with injury and are referred to as risk factors. Primary task physical characteristics include awkward posture, forceful exertions, repetitive motions, contact stress, and duration. Environmental characteristics, which involve the interaction between the worker and the work environment, include extreme temperatures, whole body vibration, noise, and lighting (Ergoweb, 2005). Scientific literature has recognized all of these risk factors as important contributors to MSDs.

Low back pain (LBP) is one of the most common and most costly WMSD and the prevalence of low back pain has become a major concern for industry (Andersson, 1981; Spengler, Bigos, Martin, Zeh, Fisher, & Nachemson, 1986; Waters, Putz-Anderson & Baron, 1998). Jobs that entail lifting, lowering, pushing, pulling, carrying and holding are often called manual material handling (MMH). Even with the development of state-of-the art production mechanisms and modern technology, many occupations still require MMH activities. The Bureau of Labor and Statistics (BLS) reported in 1994 that approximately 705,800 injury and illness cases involving days away from work resulted from overexertion and repetitive motion (as cited in Bernard, 1997). Specifically, 367,424 injuries were due to overexertion in lifting; 65% affected the back. Another 93,325 injuries were due to overexertion in pushing or pulling objects; 52% affected the back. In addition, 68,992 injuries were due to overexertion in holding, carrying, or turning objects; 58% affected the back (as cited in Bernard, 1997). Marras (2000) found that low back disorders account for approximately 16 – 19% of all worker compensation claims, but 33 – 41% of the total cost of all work compensation costs. Studies have indicated that back injury claims are commonly associated with lifting and MMH activities (Bigos, Spengler, Martin, Zeh, Fisher, & Nachemson, 1986) and estimates of annual costs for back claims have been as high as US$100 Billion. Risks involved in MMH tasks occur in a wide variety of areas in the public sector including hospitals, nursing homes, manufacturing facilities, and in the military. Researchers of the U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM) were a part of a

project aimed at identifying the most physically demanding critical tasks performed by soldiers in MOS 63 B, light wheeled vehicle mechanic. The report describes the term, physically demanding, as the subjective sensation of physical exertion, which can be related to muscular strength, endurance and power, aerobic capacity, posture, and force requirements (Lopez, Chervak, & Adika, 2001). During Desert Storm/Shield, soft-tissue musculoskeletal disorders accounted for 34% of overall injuries, and from 1991 to 1994 63% of U.S. Navy disability cases were resultant of orthopedic or musculoskeletal conditions (as cited in Lopez et al., 2001).

Table 1. Examples of Musculoskeletal Disorders (From Health Care Health and Safety Association of Ontario, 2003)

INJURY/DISORDER	SIGNS & SYMPTOMS	TYPICAL CAUSES
Back Injuries Strains and sprains of muscles and ligaments or pressure on the discs between vertebrae. Bulges or tears of outer disc fibres. Wear and tear on facet joints. Other disorders.	Pain in the back or referred down the leg. Restricted movement of back. Additional signs and symptoms dependent on type of disorder.	Manual lifting and handling (e.g., caregiver transferring client). Awkward back posture (e.g., retrieving linen from a laundry cart). Prolonged static back postures (e.g., computer operator sitting for extended periods of time). Whole-body vibration (e.g., ambulance personnel sitting in a vibrating seat while driving).
Bursitis Inflammation of the bursa (sac) found around some joints, such as the shoulder, causing an increase in the fluid within the bursa	Swelling at the site of the bursa. Pain in the affected area when the joint is moved.	Forced and repetitive movement (e.g., x-ray technicians moving overhead equipment). Awkward reaches (e.g., pulling trays along the dietary belt).
Carpal Tunnel Syndrome Pressure on the nerve that passes through the carpal tunnel.	Tingling, pain and numbness in the thumb and fingers, especially at night.	Repetitive work (e.g., entering data into a computer using awkward wrist postures). Repetitive wrist movements and use of force (e.g., dietary tasks). Work requiring force using awkward wrist postures (e.g., using power tools or retractors).
Epicondylitis Inflammation of the area at the elbow where the tendons attach to bone (e.g., tennis elbow and golfer's elbow).	Pain and swelling at the site of the disorder and when using the hand and arm. Unable to hold a coffee cup.	Repetitive extension and flexion of the elbow with rotation of the forearm. Often requiring additional force (e.g., folding laundry or preparing and/or serving food).
Muscle Strains Tears and inflammation in fibres of muscles.	Local pain and swelling. Decreased ability to use muscle.	Overuse of muscles (e.g., all health care workers).
Rotator Cuff Tendonitis of one of 4 muscles of the shoulder (supraspinatus).	Local pain at the front of the shoulder. Decreased use of the shoulder.	Overuse, repetitive outer range, above the head movements.
Tendonitis Inflammation of tendons and tendon-muscle junctions.	Pain, swelling, tenderness or redness of area around tendon.	Repetitive movement of the arm and shoulder with the arm in an awkward posture (e.g., nurses, x-ray technicians).
Tenosynovitis Inflammation of tendon sheaths.	Aching, tenderness, swelling, pain and difficulty using part affected.	Repetitive work (e.g., analytical lab work). Can be brought on by sudden increases in workload or by introduction of new process.
Ligament Sprains Tears and inflammation of ligament fibres.	Pain, swelling and limitation of joint movement.	Awkward postures forcing over-stretching of the ligaments (e.g., turning the ankle during a fall or slip).

3. Video and Computer-based Methods for Ergonomic and Biomechanical Analysis

Ergonomic assessment of physical exposures to WMSD risks requires careful attention to detail and time consuming evaluations. This process can be facilitated through the application of appropriate equipment and computer software. Computer technology can be used in several ways to enhance biomechanical and ergonomic assessments of workstations and jobs. The Center for Ergonomics at the University of Michigan has developed the 3D Static Strength Prediction Program™ (3DSSPP) which estimates the muscle strength requirements needed to perform a specified manual material handling task (University of Michigan, 2005). The computer program also provides estimates of static lumbar disc compression force and moments at the L5/S1 disc. These estimates of biomechanical loads can then be compared to baseline values that define various levels of physical stress or risk (Waters et al., 1998). The ErgoMaster® is a suite of ergonomic analysis software modules from NexGen Ergonomics Inc. The Lift Analyst provides tools, such as the Revised NIOSH Lifting Equation, to evaluate and document materials handling activities and perform biomechanical predictions for the lower back. The Posture Analyst is another module that uses tools to include Anthropometric Survey and RULA (Rapid Upper Limb Assessment), to evaluate an individual's posture as it pertains to range of motion, biomechanics, and anthropometrics (NexGen Ergonomics, 2005).

The computer system used in the present research was the PEAK Motus® System developed by Vicon Motion Systems, Inc. This is a two-dimensional (2-D) video-based motion recording and analysis system and was acquired for research use by the Human Systems Integration Laboratory (HSIL) of the Naval Postgraduate School. This computer-aided system functions as a direct posture measurement and motion measurement system. Data are acquired by using special digital cameras integrated with infrared light sources. The positions of reflective body markers are registered by the camera and the positions of the markers are calculated for each time interval of the event. A video-based

technology such as PEAK Motus® can be used for assessing human-machine interaction (for example ingress and egress), quantifying repetitive motions, and testing workstation designs. Lowe (2004) examined the accuracy of ergonomists' estimates of elbow and shoulder posture by comparing direct observation with a video-based motion reconstruction system. The basis of comparison was posture variables derived from the kinematic measurements with the PEAK Motus® system and posture variables from the ergonomists' estimates.

B. PROBLEM STATEMENT

Few published studies have investigated computer-aided observational posture analysis in relation to the risks of developing WMSDs. Little research has been done to analyze the postures of dynamic movements required in team lifting and placement (loading) tasks using video-based technology. There is also a need for more research that measures motions of the upper and lower extremities in the real work environment. Lifting studies typically examine a simple task such as to lift a box and place it on a predetermined height and the studies are performed in a controlled laboratory environment. Therefore, the current study demonstrates the use of the 2-D PEAK Motus® System to analyze postures of FCS MV-E personnel performing litter casualty loading tasks.

The present analysis is especially necessary because a vehicle specifically designed for the Army combat medic has never previously existed. Human factors and ergonomic assessments are necessary to understand and evaluate the tasks that medics must perform and their ability to safely and effectively perform those tasks. In addition, the Item Specification for the FCS MV-E states that the "vehicle shall carry three personnel" (Boeing, 2005) and the FM 8-10-6 states that a three-man squad is required to load and unload the ambulance" (Department of the Army, 2000). Yet the Operational Requirements Document (ORD) for FCS platforms states that "FCS Manned Systems must be operable by a 2-man crew - a driver and a vehicle commander" (Unit of Action Maneuver Battle Lab [UAMBL], 2005). Since the Army Transformation is

towards a lighter Army and reduced manning, this analysis also will assess the crew performing loading tasks under these two different manning conditions.

C. OBJECTIVES

The main objectives of the thesis are:

1. To demonstrate a novel approach for assessing musculoskeletal risk by using a video motion capture system in a military environment

2. To identify and describe the most physically demanding tasks and task elements performed by the medical crew

3. To evaluate the postures that personnel employ while conducting evacuation of litter casualties

4. To recommend methodologies to investigate postural risk of lifting related tasks

5. To address ergonomic issues in team lifting, and recommend ergonomic design interventions for the MV-E litter lift system

D. RATIONALE

Ergonomics is the field of study that applies scientific principles to the design and operation of work systems in which humans interact with machines, equipment, and tools with the aim of maximizing productivity and minimizing worker fatigue, exposure to hazards, and discomfort. Essentially ergonomics fits the job to the worker, not the worker to the job. This is exactly the focus of Human Systems Integration (HSI) which designs systems around the human. The current study has relevance to at least three of the seven domains as defined by the Department of Defense Instruction 5000.2- Manpower, Personnel, and Training (MPT), Human Factors Engineering (HFE), Safety and Occupational Health, Personnel Survivability, and Habitability.

1. Human Factors Engineering

This thesis evaluates the litter loading aspect of the system design of the Army's future medical vehicle. For the first time, a vehicle is being specifically designed to support the tasks of combat medics. Predecessor vehicles were typically crudely retrofitted to accommodate the transport of casualty victims and the performance of emergency treatment procedures. These systems therefore did not have efficient human-machine interface design. The physical interfaces of the new litter lift system were evaluated in this study to promote effective human performance capabilities such as safe egress and ingress, loading maneuvers, and team lifting techniques. This study also addressed the compatibility of design with ergonomics and biomechanical criteria. Specific postures were analyzed to reduce the physical workload imposed on the medics.

2. Manpower, Personnel & Training

A physical task analysis was performed to ensure that the personnel assigned to medical MOS are capable of doing required tasks. This issue is particularly important given the reduced manning initiative in the Army. The MV-E is currently assigned as a three-person crew (driver, commander, and medic assistant). If reduced to a two-person crew, the physical tasks of loading litter patients become accentuated, especially in combat situations. The study addressed personnel selection and classification, operational strength, and training concepts.

3. Safety and Occupational Health

From a review of the literature, LBP and WMSDs lead to employee absenteeism, sick leave, and permanent disability. Concern is on the rise in the Department of Defense regarding military readiness and deployability, especially since great attention has been directed towards national security over recent years. It is hypothesized that combat medics (MOS 91W) who perform casualty evacuation are at risk for musculoskeletal injuries, which would reduce their job performance capability. The study addresses safety and health hazards induced by the design of the litter lift system of the MV-E including WMSDs and physical fatigue.

E. LITERATURE REVIEW

1. Assessment of Work-related Musculoskeletal Risks

a. Task Analysis Methods

The ground vehicles portion of FCS is a critical component of the Army's transformation program and immediate design work has begun to meet the Army's schedule of fielding the first FCS unit in fiscal 2008. Therefore, there is a need to assess the requirements of the Manned Ground Vehicle variants, develop preliminary designs, and identify the components and subcomponents which will be common to all vehicle variants. Among these assessments includes a physical task analysis (or may be referred to as a physical demands analysis [PDA]) of the MedEvac. A task analysis can be defined as the study of what an operator (or team of operators) is required to do, in terms of actions to achieve a system goal (Kirwan and Ainsworth, 1992). An ergonomic approach to task analysis goes beyond the scope of traditional methods by evaluating, step-by-step, the way the human operator interacts with the machine, product, system, and work environment (Montante, 1994).

Task analyses are commonly used when designing systems. By performing a task analysis early in the system design process, the user's capabilities and limitations can be incorporated into the design of the workspace, equipment, procedures, and training. A systematic examination of the medical crew's physical tasks and daily activities is needed in order to identify controllable or preventable sources of injury. This study will focus on the physical tasks involved in the evacuation of combat casualty litter patients for the FCS MV-E. By means of personal interviews with soldiers in the MOS 91W, the most frequently performed strenuous tasks have been identified. Essential tasks that must be performed within the MOS 91 W job description, and topics included in this analysis, are strength, mobility, environmental, and work organization demands (Health Care Health & Safety Association of Ontario, 2003). Strength demands explore manual lifting, pulling/pushing, carrying, handling, fingering/gripping and reaching (Bos, Kuijer, & Frings-Dresen, 2002). The demands of mobility consist of describing the sitting, standing, walking, running,

climbing, balancing, bending and stooping required of the worker. Environmental demands include work features such as indoor/outdoor, hot/cold, vibration, noise, dust, and confined spaces. Lastly, work organization demands involve shift work, individual and teamwork (Bos et al., 2002; Ergoweb, 2005).

b. Posture-based Methods

A range of methods exist for assessing exposure to risks associated with work-related musculoskeletal disorders. These assessments also reveal parts of a job or tasks within a job that may be hazardous. Li and Buckle (1999) provide an overview of existing posture-based techniques that can be used within the assessment of physical workload and associated exposure to work-related musculoskeletal risks. The review includes observational methods, instrumental or direct methods, self-reporting, and other psychophysiological methods.

(1) Observational Methods. The earliest observational methods recorded human postures by way of paper and pen dating back to the seventeenth century. The Ovako Oy Steel Company later developed the Ovako Working Posture Analysing System (OWAS) which describes movements around the body as being a bending, a rotation, an elevation, or a position type of movement. The OWAS is a rather simple technique since the recording procedures requires only a few seconds and can be used in conjunction with a random schedule of observations to obtain a summary description of posture (Li & Buckle, 1999). The Rapid Entire Body Assessment (REBA) has been found to be a practical tool especially for evaluating active, non-sedentary tasks where postures are dynamic or gross changes in position occur. A posture or activity is selected and body alignment is scored using diagrams. Then the activity is combined with a load score. This assessment also provides suggestions with action levels for ergonomic interventions. Going a step further, a method that has shown sensitivity to the change in exposure before and after an ergonomic intervention is the Quick Exposure Check (QEC) system developed by Li and Buckle (as cited in Li & Buckle, 1999). The QEC assesses the effectiveness of whether a workplace or job redesign has reduced the risk exposure level for

potential WMSDs. In recent years, videotaping and computer-aided observational methods have become widely used to avoid observer bias. For example, 2-D or 3-D motion systems record body posture and movement in two- or three-dimensional planes through a video-recording system. The advantages of such systems are that several joint segment movements can be recorded simultaneously for different tasks and data analysis is simplified with the help of advanced software.

(2) Direct Methods. Direct methods of posture assessment have been done manually with hand-held devices (e.g. goniometer or inclinometer) or continuously with electric equipment. Several studies have been done using a device called a Lumbar Motion Monitor (LMM) which measures the motion in the lumbar and thoracic sections of the spine. One study described the working postures and forces applied as firefighting crews performing paramedic functions (FF/P) performed simulated transport tasks (Lavender, Conrad, Reichelt, Meyer & Johnson, 2000). Using the most frequently performed strenuous emergency rescue tasks identified in a survey, ten two-person teams of FF/P were videotaped while performing tasks bed to stretcher transfer, stretcher to gurney transfer, and three stair descent tasks. The most extreme postures were shown to occur during the "initial lift" portion of the transport of a patient down the stairs using a backboard. In the "initial lift", the board was lifted from the floor to waist level which resulted in the trunk being maximally flexed, elbows fully extended, and knees flexed approximately 90°. In other analysis of fire fighters, 49% of overexertion related injuries had a specific cause of lifting and 42% of the injuries with a cause of overexertion affected the lower back (Walton, Conrad, Furner & Samo, 2003).

Combining observational methods with direct recording methods is a growing trend among body motion studies. This approach was applied to a study where maintenance workers were observed performing 60 minutes of dynamic and static work. Observational recordings were used to calculate the average percentage of time spent with the trunk in a bent position during a normal workday (Burdorf, Derksen, Naaktgeboren, & van Riel, 1992).

Significant correlations between direct observation and continuous measurement ($r_{s1} = 0.62$ and $r_{s2} = 0.57$). However, large differences were found between the data for individual subjects. The researchers assume that the cause of these differences may be from less precision via direct observation if trunk movements are "concentrated in the critical range around the borderline of 20° flexion/extension" (Burdorf et al., 1992). Applying different definitions of angles of trunk bending is offered as an alternative explanation. A study performed by the Army Research Institute of Environmental Medicine (USARIEM) specifically investigated how a harness would improve soldier performance during and after litter carrying. By simulating a mass casualty task and a removal from a remote site, a repeated measures design was used to determine differences in harness use, team size, and gender (Rice, Sharp, Tharion & Williamson, 2000).

(3) Self-Reporting Methods. This type of assessment involves detailed subjective and performance-based measurement. This methodology is the most common due to the ease of use and face validity. Rating scales, questionnaires, body maps, interviews, and checklists are all examples of this form of investigation. Some researchers rely solely on subjective perceptions while others maintain that the self-report approach has insufficient validity and reliability (Li & Buckle, 1999).

(4) Other Methods.

(a) Psychophysical Methods.

The psychophysical approach takes into consideration the human response to work tasks and is based on widespread scientific examination of MMH tasks to determine safe lifting weights. Snook and Ciriello lead the way in this method by giving participants control over the weight being lifted in order to identify an individual's length of time to sustain work without becoming strained, unusually tired, weak or out of breadth (as cited in Townley, Hair, & Strong, 2005). The data used in these trials yielded tables of maximum acceptable weight of load (MAWL) – commonly referred to as the "Snook Tables" - for both male and female workers.

(b) Biomechanical Methods. To consider the mechanics of the muscular activity and the effect of different stresses on the body during work tasks,

biomechanical methods have often been employed. This type of approach is key since it considers the physical characteristics of the user (e.g. height and weight), load (magnitude and force acting on each hand), and posture (the positioning of major body joints and segments). For example, a study analyzed how well and to what degree of exposure five trunk motion and workplace factors were associated with an increase risk of low back disorder (LBD) documented three-dimensional angular position, velocity, and acceleration characteristics of the lumbar spine (Marras et al., 1995). Results of the study indicated that trunk velocity was the strongest predictor among the trunk motion factors. Trunk velocity characteristics (in each of the cardinal planes) were often more predictive of LBD than position, range of motion, or acceleration. Studies have also suggested that there is an increase in lumbar stress when lifting objects near the floor (Chaffin, Andersson, & Martin, 1999). Townley et al. (2005) quantified lifting hazards by using a two-dimensional biomechanical model to determine the compressive and shear forces exerted on the spine. The model was also used for extreme posture positions. However, several important assumptions were made when using this 2D method including: minimal trunk rotation while performing the tasks, low task duration and frequency.

F. LIMITATIONS

The current study does have certain factors that may restrict the application of the results. First, due to structural capability of the MV-E mockup at the time of data collection, the litter lift teams loaded empty litters without any simulated load. The simulation environment was incapable of withstanding appropriate weight on the loading trays. Second, the electrical mechanism of the litter lift system had not been installed, so participants were not able to fold the loading trays in the stow position nor lower or raise the upper litter tray to the load and ready position respectively. However, in a worst case scenario, litter casualty victims would be loaded on the upper tray from the ready position. Another limitation of the mockup was that the metal braces on the frame prevented the litter to be slid easily onto the tray. Also, civilians were used to perform the task simulation due to time limitations and the nonavailability of soldier participants.

II. METHODOLOGY

A. PARTICIPANTS

A total of five people (3 males, 2 females) were recruited to participate in this study. Two of the individuals were U.S. Army soldiers and one had a Military Occupational Specialty (MOS) 91W Combat Health Specialist. The remaining participants did not have any prior enlisted military experience and were not trained in casualty evacuation procedures. In addition, the 91W medic also served as a subject matter expert (SME) during this study. Prior to participation, all volunteers were briefed on the objectives of the study, the tasks they would perform, procedures, and their right to withdraw at any time. The two soldiers were dressed in their Army uniforms while the rest of the participants had civilian clothing.

B. APPARATUS

The simulation environment for this study was a plywood vehicle mock-up of the FCS MV-E located at BAE Systems in Santa Clara, CA. It must be noted that the mock-up used in this study was a work-in-progress. Also due to construction limitations of plywood, there was a 5-inch step at the base of the entrance to the vehicle. Participants used a standard NATO Decontaminable litter, which has been developed to replace the canvas litters currently in use among military units. The new litter is similar to the basic components of the canvas collapsible litter which includes: two straight, rigid, lightweight aluminum poles; a fabric cover; and four wooden handles attached to the poles (Department of the Army, 2000). The major difference is that the decontaminable litter is made of a monofilament polypropylene that has high tensile strength and low elasticity. The fabric does not absorb liquid chemical agents, is not degraded by decontaminating solutions, and the carrying handles are adjustable to allow for litter bearers' comfort (USACHPPM Tech Guide, 2002). Due to limited structural capability of the current mockup to withstand

appropriate weight, the litters did not have a simulated load. Instead, empty litters were used.

During each task simulation, digital video data were recorded. The video was later analyzed using the (2-D) motion capture PEAK Motus® Software version 8.4 developed by Vicon Motion Systems, Inc. The video camera used was a Panasonic PV-GS55 Digital Palmcorder® MultiCam™ Camcorder.

C. TASK ANALYSIS

Soldiers with MOS 91 W health care specialists have a variety of duties to perform. Given the complexity of their tasks and the fact that tasks change depending on operational situation, it is difficult to define all medics' tasks. Several phases were required in order to identify tasks that expose medics to ergonomic risks. The first phase may be referred to as a descriptive phase, which involved collection and review of critical task documents for the MOS 91 W. A general understanding of all jobs performed by these specialists was achieved and physical requirements to accomplish the tasks were reviewed. The next phase involved conducting interviews and questionnaires. Discussions with SMEs captured clear descriptions of physically strenuous job tasks and associated roles. This task analysis procedure also involved accompanying BAE employees to Fort Sam Houston, Texas where interviews were conducted with MOS 91W soldiers to identify the most frequently performed, physically strenuous activities performed during medical evacuations (see Appendix B). This information gathered was used to structure the focus of this study.

The scope of this study was limited to the loading tasks involved within evacuating litter casualty victims. The focus was on the medical evacuation tasks, which is task step number 2 part C according to the ARTEP for the Medical Platoon (Army Training and Evaluation Program [ARTEP], 2002). A section of this ARTEP is displayed in Table 10 of Appendix A (note that this is one continuous table). The tasks were broken down into sub-tasks (refer to

Table 2). The investigator then analyzed each task to determine the postural demands of each task element.

Table 2. Task sequence

Task Number	Task	Sub-tasks
1	***Load Sponson Litter***	Lift and carry litter and approach ramp Begin ramp ascent Load litter
2	***Load Upper Litter***	Slide out litter tray Lift and carry litter to vehicle Begin ramp ascent Load litter Slide in litter tray
3	***Load Bottom Litter***	Slide out litter tray Lift and carry litter to vehicle Begin ramp ascent Load litter Slide in litter tray
4	***Load Middle Litter***	Slide out litter tray Lift and carry litter to vehicle Begin ramp ascent Load litter Slide in litter tray

D. STUDY DESIGN AND PROCEDURES

For this study an assessment of the litter loading process using 2-person and 3-person teams was accomplished by task simulations in the FCS MV-E mockup. Only the loading process was analyzed since that is the most critical component in casualty evacuation from the battlefield. The FCS MV-E is currently assigned as a 3-person crew. The analyst was informed that this job is not normally performed by the MV-E crew since assistance is typically at the casualty pickup site. Yet, with the ongoing initiative from the Army to reduce manning, this vehicle may become a 2-person crew. It is important to assess the

ability of the two different manning levels to perform the job adequately and without increased risk of injury. Participants loaded the maximum capacity for the MV-E in order to simulate a worst case scenario – i.e., two teams executed the evacuation of four litter casualties. The video data were collected with team size at two levels (a 2-person team and a 3-person team), and the height of the load at the destination of lift had four levels (sponson, upper, bottom, middle). The destination height refers to the location of loading each litter into the vehicle. The video data analysis provided measures of trunk motion characteristics and horizontal lift distance. Trunk motion characteristics consisted of trunk angle, trunk velocity, and trunk acceleration. The maximum horizontal distance of the load from the spine also was measured.

1. Video Data Collection

When using a motion capture system, the most ideal and efficient camera views must be decided. The best optical views are especially important to establish when 2-D software is used to analyze postures. The motion that was captured was restricted to a plane, i.e. the motion of the participants was perpendicular to the optical axis. In this case, three different camera views were used to capture as many of the postures as possible - rear of the vehicle mockup, side view of the ramp, and front of the vehicle mockup. Thus, the participants repeated most of the tasks from each different camera view. Prior to camera setup, some preliminary actions were taken to ensure that the mockup environment was ready. For example, the mockup was moved away from any wall or obstruction in order to allow ample room for entry and exit into the vehicle.

The study occurred over a two-day period. Participants were randomly assigned to one of two teams: a 3-person team (Team ALPHA) or a 2-person team (Team BRAVO). Data were collected for Team ALPHA on Day 1 and for Team BRAVO on Day 2. Before data collection began, volunteers were briefed on the objectives of the study, the tasks that they would be asked to perform, procedures for completing the tasks, and the freedom to withdraw at any time. First, participants were first assigned roles in each litter lift team. The “Head” role referred to the location of the head a casualty victim on the litter and the “Foot”

role referred to the where the feet of a casualty victim on the litter would be located (refer to Table 3). It is standard operating procedure, according to Army doctrine, to load the litter casualties head first (Department of the Army, 2000). Participants in Team ALPHA at the head of the litter used a one-hand hold to carry the litter; while both members of Team BRAVO used a two-handed lift technique. Reflective markers were placed on each participant. See Table 4 for participant summary information.

Table 3. Summary of participant duty roles

	Participant's Role	Description
Team ALPHA	Head 1	Located at the head of the litter on the right side
	Head 2	Located at the head of the litter on the left side
	Foot	Located at the rear of the litter
Team BRAVO	Head	Located at the head of the litter
	Foot	Located at the rear of the litter

Table 4. Participant summary data

	Participant Number	Participant's Role	Gender	Height (m)	Weight (kg)
Team ALPHA	1	Head 1	Female	1.73	90.72
	2	Head 2	Female	1.63	56.70
	3	Foot	Male	1.82	117.93
Team BRAVO	4	Head	Male	1.88	95.25
	5	Foot	Male	1.63	79.38

Each team was given the opportunity to do a practice trial of loading each litter location (sponson, upper, bottom, and middle).

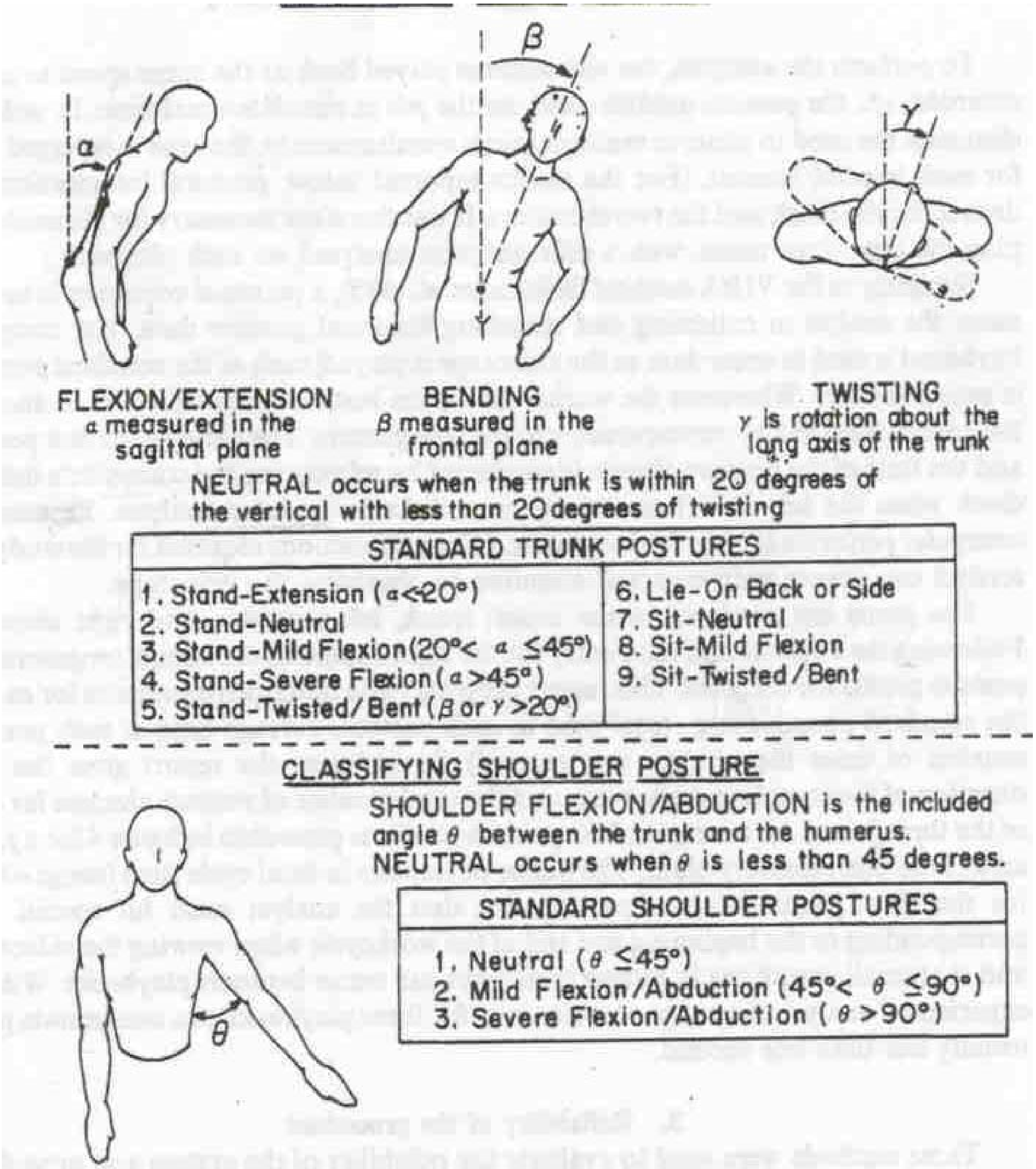
The maximum horizontal distance was a workplace characteristic that was measured for each participant performing each task. A tape measure was used to calculate the furthest distance of the load (the litter in this case) from the participant's trunk. Finally, each participant completed a brief questionnaire

about the physical demands and postural constraints for each task in the simulation.

2. Posture Classification

As mentioned earlier, the evidence from epidemiological studies suggests that posture plays a significant role in the development of WMSDs. A video motion capture technique was used to better understand the effects of body posture on the major joints of the musculoskeletal system. By using this approach, the human operator was first videotaped performing the task and then the investigator observed a replay of the videotape. The postures adopted by the medical crew in the task simulation were carefully analyzed on an individual basis and determined by the position of the trunk, upper limb, and neck according to the micropostural classification system developed by W. Monroe Keyserling (Keyserling, 1986). This classification system provides a simple method for analyzing jobs to identify awkward postures that may lead to LBD or other WMSDs. No tasks in the simulation were performed while seated, therefore only the posture classification for standing workers was used. The trunk is considered to deviate from the neutral upright posture and be at risk of injury if it is extended, flexed, bent, or twisted more than 20° (as cited in Keyserling, 1986). Specifically, mild trunk flexion occurs when trunk angle is between 20° and 45°; while severe trunk flexion is when the trunk angle is greater than 45° (see Figure 2). Unlike the OWAS, Keyserling's posture classification system independently describes the left and right shoulders. The shoulder is considered to deviate from neutral when it is flexed or abducted more than 45°. Classifications by Genaidy et al. also agree that the lower back is a severely flexed when the angle measured is greater than 45° (as cited in Genaidy, Al-Shedi & Karwowski, 1994).

Figure 2. Posture classification (From Keyserling, 1986)



The postures for each member in both teams were carefully examined using the captured video clip. With the capability of PEAK Motus® it is possible to analyze movements of body segments on a frame by frame basis. Included in the results section of this study, are descriptions of the lower back postures,

shoulder, and arm movements which deviated from the neutral position while performing the task simulation.

III. RESULTS AND DISCUSSION

A. ANALYTICAL APPROACH

1. Postural Analysis

The postural data were extracted from the videotapes using the PEAK Motus® software. Each of the four tasks was reviewed to obtain bi-planar postural data for the trunk, shoulders, and neck. However, due to 2-D software limitations and difficulty to track markers that were unseen, only trunk-to-vertical angles in the saggital plane were used for the majority of data analysis. Although lateral bending of the trunk and rotation of the trunk did occur, the current equipment and vehicle mockup configuration did not allow for this data to be captured accurately.

2. Summarizing Results

Table 5 indicates whether or not there was available trunk angle data present to be used in data analysis. The decision was made based on whether the motion needed to perform each task was within a two-dimensional plane and markers remained in the field of view throughout the motion.

Table 5. Summary of available data for task simulation

		Task 1 - Sponson	Task 2 - Upper	Task 3 - Bottom	Task 4 - Middle
ALPHA 3 person team	**Head 1**	no	yes	yes	yes
	Head 2	yes	yes	yes	yes
	Foot	no	no	no	no
BRAVO 2 person team	**Head**	no	yes	yes	yes
	Foot	yes	no	no	no

Due to the limiting factors previously discussed, exploratory data analysis was the best way to summarize this set of data. There was not sufficient data to conclusively quantify the risk of developing musculoskeletal injury based on posture analysis. Specifically, rankings of trunk velocity and trunk acceleration were not done since there appears to be no standard by which to classify values. After the video data were processed, PEAK Motus® provided 2-D angular trunk

velocity and 2-D angular trunk acceleration for each individual performing a particular task. However, there was no statistical analysis performed regarding trunk velocity or trunk acceleration for the task simulation. As shown in Table 5, there was not enough available data to make statistically sound comparisons between the two teams. Also there was inadequate data across tasks for statistical comparisons within subjects.

Measures of central tendency and measures of spread were evaluated for the ranks of severe trunk angles in Team Alpha and Team Bravo. The Mann-Whitney U non-parametric test was to analyze the postural data and to determine significance of trunk angle severity for both teams.

B. RESULTS

1. Task Analysis

The results of the task analysis performed are presented in Table 6. Refer to Appendix A for more information on medical evacuation jobs.

Table 6. FCS MV-E physical task analysis for loading litter casualties

	Ambulance Squad, Medical Platoon		
FCS Medical Evacuation Vehicle (MV-E) Loading Task Analysis			
	Ground Ambulance Evacuation Support Tasks		
Task Step #	**Task Summary**	**Activity**	**Postural Characteristics**
2	Ambulance team evacuates patients		
2.1	Loads the ambulance by loading litter patients and assisting the ambulatory patients		
2.1.1	Determine ambulance load capacities		
2.1.2	Determine the loading sequence		
2.1.3	Load sponson litter casualty		
2.1.3.1	Lift and carry litter from pickup point	squatting, kneeling, one-hand and two-hand holds	trunk & knee flexion, shoulder abduction, power hand grip
	Approach and climb ramp	raising leg 10.35 m from floor, walking on inclining surface, body rotation and hand-off	knee and ankle flexion, raised shoulders, trunk rotation
	Place litter on right hand side sponson	reaching forward with both arms, bending forward to place litter	trunk flexion, shoulder flexion & abduction
2.1.4	Load upper litter casualty		
	Slide upper tray to ready position	pulling tray towards upper body	wrist extension, forearm supination
	Lift and carry litter from pickup point	squatting, kneeling, one-hand and two-hand holds	trunk & knee flexion, shoulder abduction & extension, power hand grip
	Approach and climb ramp	raising leg 10.35 m from floor, walking on inclining surface, body rotation and hand-off	knee and ankle flexion, raised shoulders, trunk rotation
	Place litter on upper tray	reaching forward with both arms, raising hands above shoulder height	shoulder abduction & flexion, elbow flexion, wrist extension
	Slide upper tray to stow position	pushing tray away from upper body	wrist extension, forearm pronation

Table 6 cont. FCS MV-E physical task analysis for loading litter casualties

	Ambulance Squad, Medical Platoon		
FCS Medical Evacuation Vehicle (MV-E) Loading Task Analysis			
	Ground Ambulance Evacuation Support Tasks		
Task Step #	**Task Summary**	**Activity**	**Postural Characteristics**
2.1.5	Load bottom litter casualty		
	Slide bottom tray to ready position	bending from waist to pull tray out	wrist extension, forearm supination, trunk flexion
	Lift and carry litter from pickup point	squatting, kneeling, one-hand and two-hand holds	trunk & knee flexion, shoulder abduction & extension, power hand grip
	Approach and climb ramp	raising leg 10.35 m from floor, walking on inclining surface, body rotation and hand-off	knee and ankle flexion, raised shoulders, trunk rotation
	Place litter on bottom tray	reaching forward with both arms, back bent forward	wrist extension, forearm supination, neck extension, trunk flexion
	Slide bottom tray to stow position	bending from waist to push tray in	wrist extension, forearm pronation, trunk flexion
2.1.6	Load middle litter casualty		
	Slide middle tray to ready position	back slightly bent to pull tray out	wrist extension, forearm supination
	Lift and carry litter from pickup point	squatting, kneeling, one-hand and two-hand holds	trunk & knee flexion, shoulder abduction & extension, power hand grip
	Approach and climb ramp	raising leg 10.35 m from floor, walking on inclining surface, body rotation and hand-off	knee and ankle flexion, raised shoulders, trunk rotation
	Place litter on middle tray	reaching forward with both arms, back bent forward	shoulder abduction & flexion, elbow flexion, wrist extension
	Slide middle tray to stow position	back slightly bent to push tray in	mild trunk flexion, wrist extension, forearm pronation

2. Video Data Summary Results

The results are the summary statistics of the raw data provided by PEAK Motus® (see Figure 3). For Task 1, the only available data is for the Head 2 member of the 3-person team and the Foot member of the 2-person team. The average trunk angles for both teams exceed 45 degrees, which according to Keyserling's posture classification system, are classified in the severe trunk posture classification (Keyserling, 1986).

Task 2 did not appear to expose the participants of both teams to severe trunk postures. Two individuals in the 3-person team assumed an average trunk angle less than 45 degrees and one individual in the 2-person team had an average trunk angle of only 1.4 degrees. The Head member of Team Bravo also appeared to have slight trunk extension while loading the litter on the top frame (minimum trunk angle = -4.3 degrees).

Team members appeared to assume the greatest degree of trunk flexion while performing Task 3. The Head 1 member of Team Alpha had an average trunk angle of 113 degrees which greatly exceeds neutral standing trunk posture. The Head 2 member of Team Alpha and the Head member of Team Bravo both assumed average trunk postures that are within the severe trunk posture classification (57° and 85° respectively).

For Task 4, participants in the 3-person team loading the middle frame had severe trunk angles (with averages of 56 and 63 degrees), while one individual of the 2-person team did not assume a trunk angle of greater than 45 degrees while performing this task.

Figure 3. Summary statistics for each task

Summary Statistics of Trunk Angles*

TASK 1: Sponson

	Team ALPHA			Team BRAVO	
	Head1	**Head2**	**Foot**	**Head**	**Foot**
Minimum	---	31.81	---	---	67.70
Maximum	---	79.43	---	---	82.85
Average	---	62.88	---	---	77.19
Standard Deviation	---	13.26	---	---	4.70

TASK 2: Top

	Team ALPHA			Team BRAVO	
	Head1	**Head2**	**Foot**	**Head**	**Foot**
Minimum	15.68	5.24	---	-4.35	---
Maximum	18.05	47.51	---	8.64	---
Average	17.24	26.41	---	1.37	---
Standard Deviation	0.63	12.29	---	3.12	---

TASK 3: Bottom

	Team ALPHA			Team BRAVO	
	Head1	**Head2**	**Foot**	**Head**	**Foot**
Minimum	100.56	6.22	---	79.70	---
Maximum	126.24	84.23	---	86.67	---
Average	112.80	57.04	---	85.33	---
Standard Deviation	7.33	20.50	---	1.87	---

TASK 4: Middle

	Team ALPHA			Team BRAVO	
	Head1	**Head2**	**Foot**	**Head**	**Foot**
Minimum	43.81	45.53	---	4.38	---
Maximum	61.24	75.38	---	39.64	---
Average	55.50	63.27	---	16.57	---
Standard Deviation	3.94	5.71	---	9.27	---

--- = No Data Available

* All values are trunk to vertical angle

3. Proportion of Severe Trunk Angles

The data were also summarized using proportion of severe trunk angles for each participant performing each task. This proportion was calculated by dividing the number of severe trunk angles by the total number of data points. Figure 4 shows the resulting individual proportions for each task.

Figure 4. Percentage of severe trunk angles for each task

Summary of Proportion of Severe Trunk Angles*

TASK 1: Sponson

	Team ALPHA			Team BRAVO	
	Head1	Head2	Foot	Head	Foot
Ranks	---	81.30%	---	---	100%

TASK 2: Top

	Team ALPHA			Team BRAVO	
	Head1	Head2	Foot	Head	Foot
Ranks	0%	1.31%	---	0%	---

TASK 3: Bottom

	Team ALPHA			Team BRAVO	
	Head1	Head2	Foot	Head	Foot
Ranks	100%	80%	---	100%	---

TASK 4: Middle

	Team ALPHA			Team BRAVO	
	Head1	Head2	Foot	Head	Foot
Ranks	99.60%	100%	---	0%	---

--- = No Data Available

* All values are trunk to vertical angle

4. Maximum Horizontal Distance

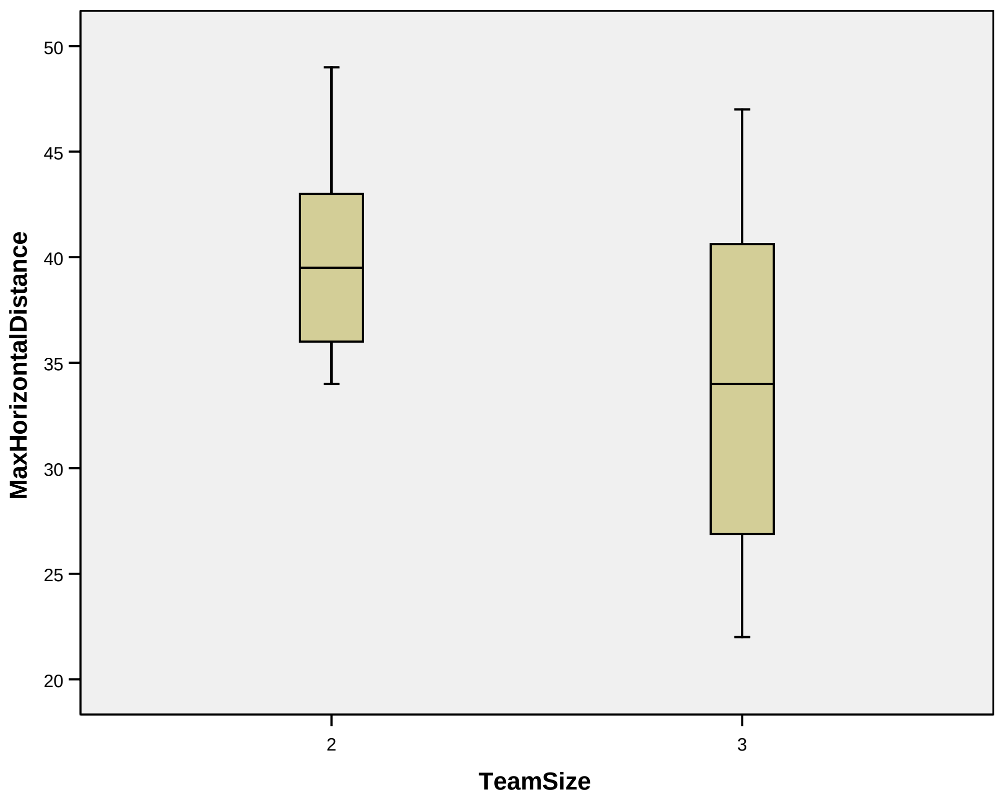
The maximum horizontal distance of the litter from each participant's trunk was measured in all tasks. Table 7, shows the values for the furthest distance of the litter for each individual team member while performing each task. As

evidenced in Figure 5 below, individuals in the 2-person team had higher distances than members of the 3-person team for all tasks.

Table 7. Maximum horizontal distances for each task (inches)

		Task 1 - Sponson	**Task 2 - Upper**	**Task 3 - Bottom**	**Task 4 - Middle**
ALPHA 3 person team	**Head 1**	47.0	31.0	44.5	42.0
	Head 2	25.0	26.5	39.3	33.5
	Foot	36.0	27.3	34.5	22.0
BRAVO 2 person team	**Head**	40.0	35.0	40.0	34.0
	Foot	49.0	39.0	46.0	37.0

Figure 5. Boxplot of maximum horizontal distance (inches)



The postures for each member in both teams were carefully examined using the captured video clip. With the capability of PEAK Motus® it is possible to analyze movements of body segments on a frame by frame basis. Below is a

description of the lower back postures, shoulder, and arm movements which deviated from the neutral position while performing the task simulation.

5. Task 1 Sponson Litter Loading Postures

Awkward trunk postures occurred for the Head 2 team member of Team Alpha while performing each task. For example, loading the Sponson (Figure 6) resulted in trunk flexion and elbow flexion. It was observed that the litter was loaded with the lower arm supinated which did allow for minimal wrist extension. The degree of back forward bending (approximately 79°) at this point of performing the task, placed the crew member at risk for back injury since the angle exceeded 45° (see Figure 7).

Figure 6. Head 2 sponson loading- video capture (l) and spatial model (r)

Figure 7. Head 2 peak trunk angle while loading sponson

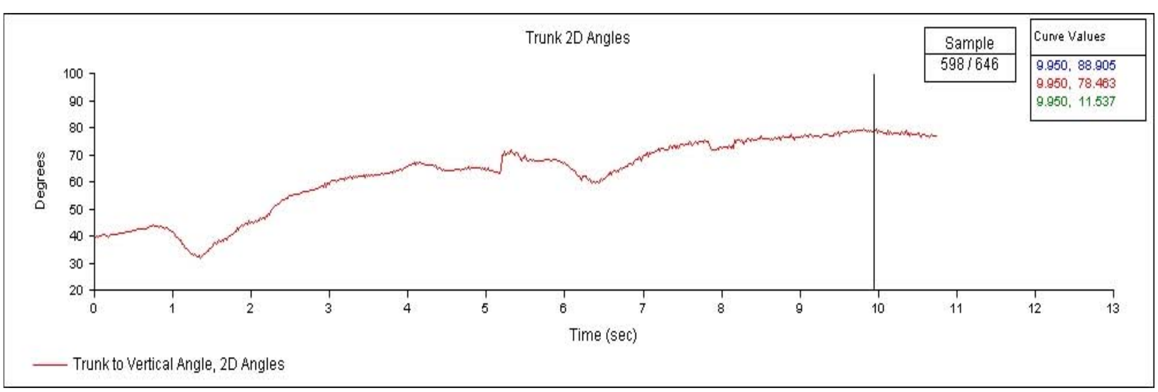


Figure 8 shows forward trunk flexion for the Foot member of Team Bravo while performing this task. The shoulders of the participant were slightly abducted and extended as he leaned forward to place the litter in the vehicle.

Figure 8.   Team Bravo Foot sponson loading

6.   Task 2 Upper Litter Loading Postures

Figure 9 shows the Head 1 member of Team Alpha loading the upper frame and assuming a slight trunk flexion at the start of litter placement on the frame. The photo also captures the shoulder flexion that the crew member assumed to reach across the frame to grasp the litter handle.

Figure 9.   Head 1 upper loading

The posture that was repeatedly observed for the Foot team member of both teams was shoulder and wrist extension (see Figure 10). This occurred when the participants raised their arms above shoulder height to load the litter on the upper frame. Figures 11 and 13 also show shoulder abduction when loading the litter onto the metal frame before sliding into place. An accompanying graph (Figure 12) illustrates the shoulder angles that occurred throughout Task 2. A vertical marker was drawn to indicate the peak shoulder angles (left shoulder ≈ 69° and right shoulder ≈ 66°). According to Keyserling's standard classification system, these are mild shoulder abduction postures (Keyserling, 1986).

Figure 10. Team Alpha and Team Bravo Foot members loading upper litter

Figure 11. Foot upper loading- video capture (l) and spatial model (r)

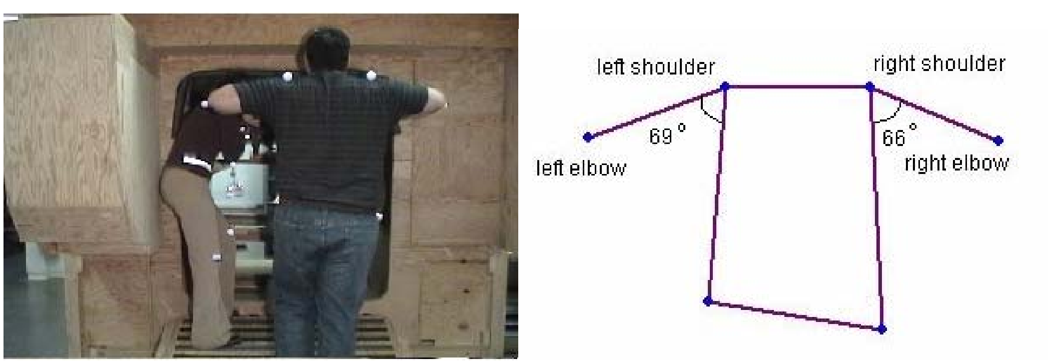


Figure 12. Team Alpha Foot peak shoulder angles while loading upper litter

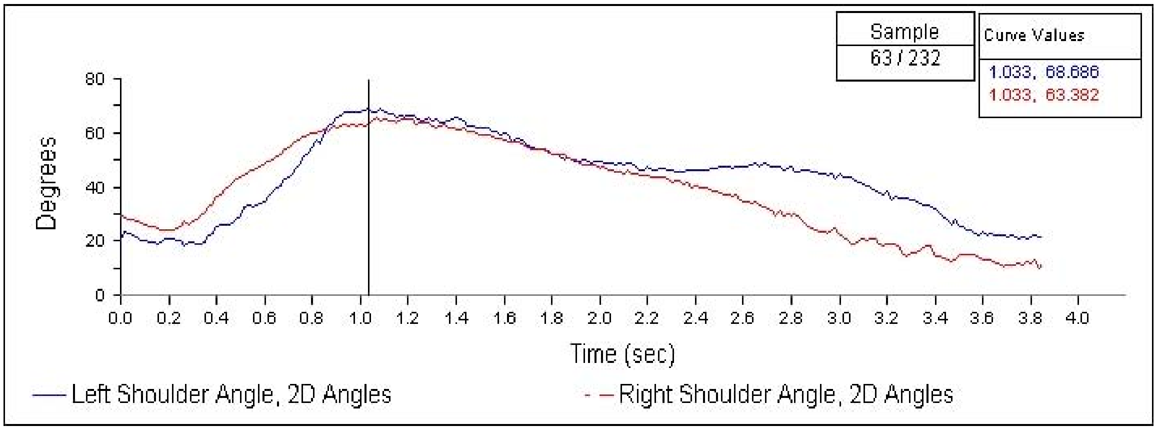


Figure 13. Team Bravo Foot shoulder abduction while loading upper litter

The crew members must enter the vehicle to load the litters via a ramp. The Figure 14 is provided to show an example of the considerable step-up required to enter the vehicle.

Figure 14. Team Bravo Foot stepping up on ramp while loading upper litter

Another awkward body posture observed was when the Head member of Team Bravo prepared to place the litter onto the upper frame. In the 2-person team, the individual at the head of the litter always entered the vehicle face-forward while holding the litter behind the back with both hands on the handles. Once the litter bearer stepped inside the vehicle, he stopped to turn around and face the direction of the litter. Therefore, rotation occurred about the long axis of the trunk. He briefly placed one litter handle on his lower back and turned around to grab the other litter handle (see Figures 15 and 16) . This maneuver was not observed during the Team Alpha's loading tasks since there was another person present to hand over the litter.

Figure 15. Team Bravo Head awkward maneuver while loading upper litter

Figure 16. Team Bravo Head trunk rotation while loading upper litter

7. Task 3 Bottom Litter Loading Postures

The most extreme posture for the Head 1 member of Team Alpha occurred while loading the litter on the bottom frame (see Figure 17). In this posture, the maximum horizontal distance of 45 inches was achieved and the greatest flexion of the back occurred. The participant reached across the bottom frame to properly set the litter onto the loading tray. One factor that may have contributed to this awkward posture was that the bottom frame was on the floor and material handling motions that occur below knee height maximize the horizontal distance resulting in greater compression on the L5/S1 disc (Chaffin et al., 1999). A squatting position may reduce this postural risk; however the shape and size of the load and the limited space available in the vehicle make squatting difficult.

Figure 17. Head 1 loading bottom litter

The accompanying graph (Figure 18) indicates the peak trunk angle achieved while performing the bottom loading task (approximately 125°). Figures 19 and 20 are graphs of angular trunk velocity and angular trunk acceleration (respectively) while Head 1 performed Task 3.

Figure 18. Head 1 peak trunk angle while loading bottom litter

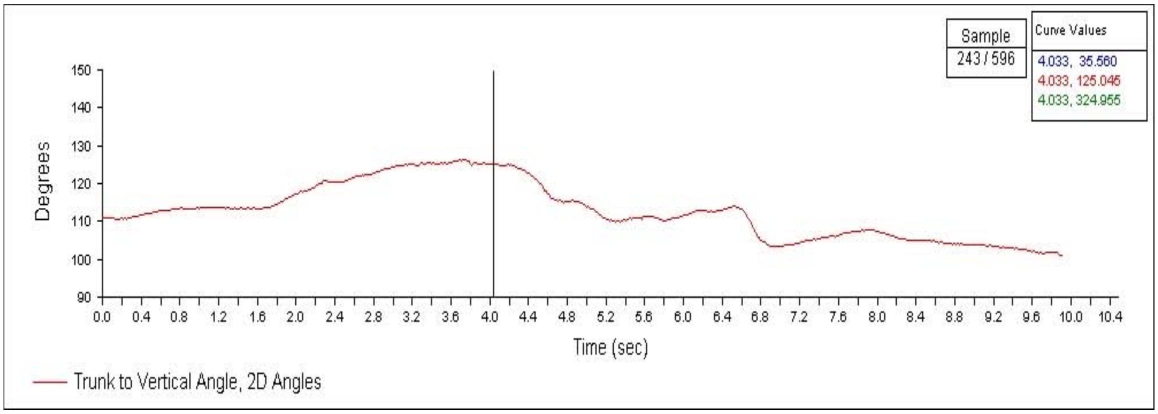


Figure 19. Head 1 angular trunk velocity while loading bottom litter

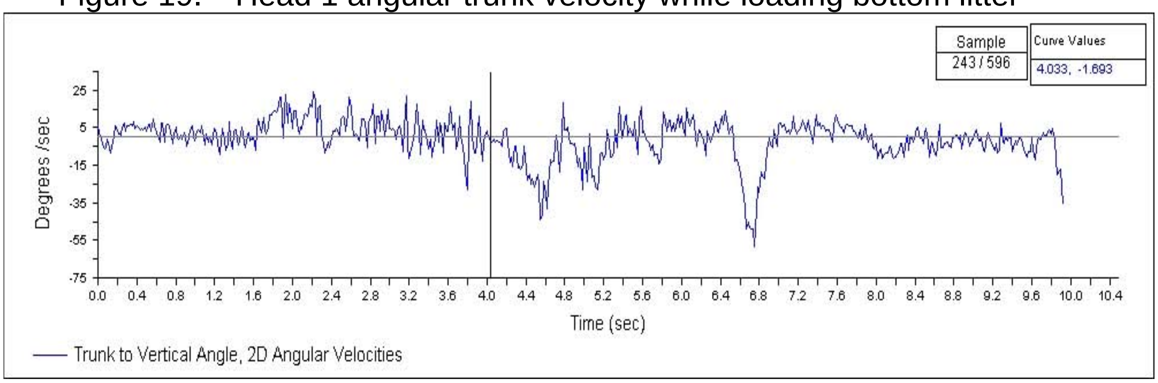
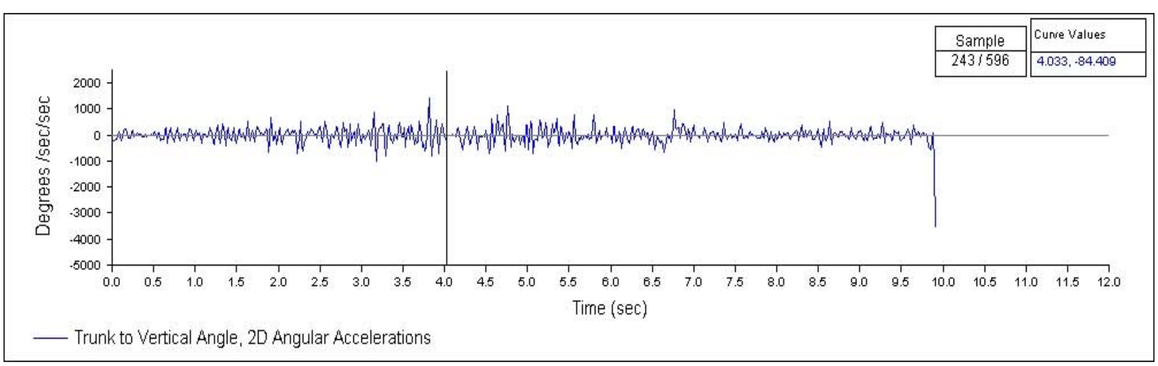


Figure 20. Head 1 angular trunk acceleration while loading bottom litter



The implications of angular trunk velocity and acceleration are unknown. Specifically, it is not certain whether higher trunk velocities and accelerations lead to low back injuries. Nonetheless, Table 8 reports the angular trunk velocity and acceleration for Head 1 while loading the bottom litter.

Table 8. Summary statistics for Head 1 loading bottom litter (deg/sec and deg/sec^2)

	Trunk Velocity	Trunk Acceleration
Minimum	-58.29	-3546.41
Maximum	24.06	1397.66
Average	-1.08	-10.36
Standard deviation	11.03	306.28

The Head team member in Team Bravo also assumed severe trunk flexion while loading the litter onto the bottom frame (Figures 21 and 22). However, it was observed that instead of using both handles and reaching across the frame to place the load, the participant holds the litter from the middle. The angular trunk velocities and angular trunk accelerations were provided for this task (Figures 23 and 24) and are summarized in Table 9.

Figure 21. Head loading bottom litter

Figure 22. Head peak trunk flexion loading bottom frame

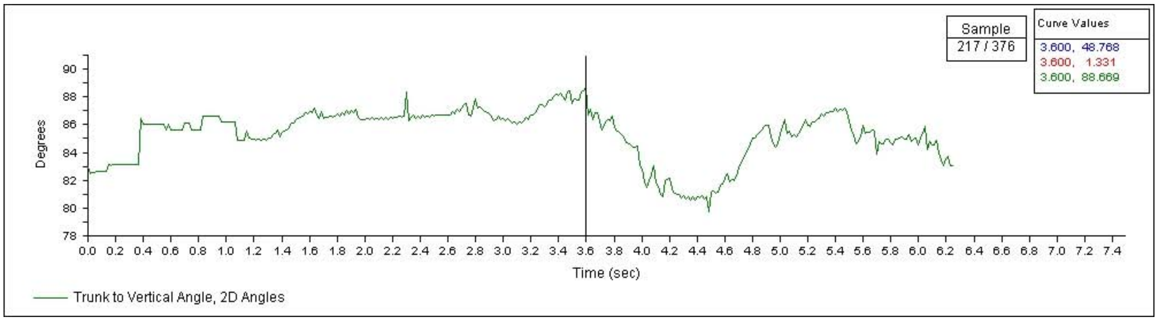


Figure 23. Head angular trunk velocity while loading bottom litter

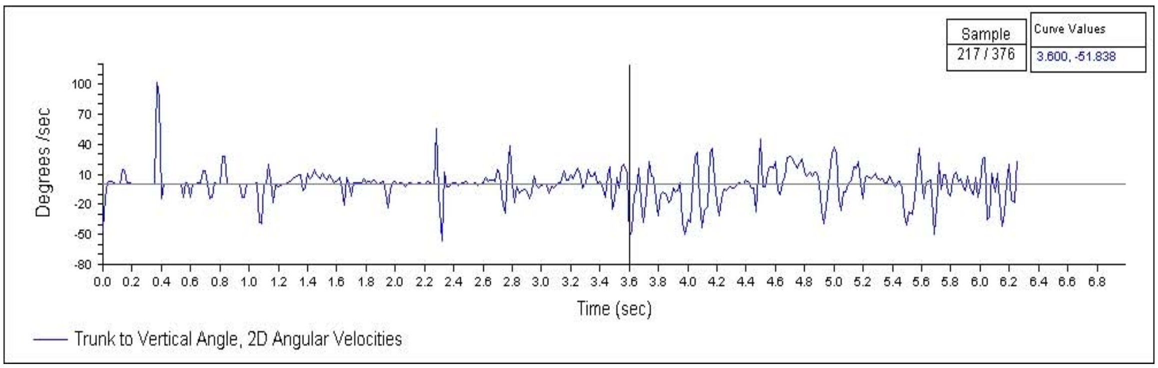


Figure 24. Head angular trunk acceleration while loading bottom litter

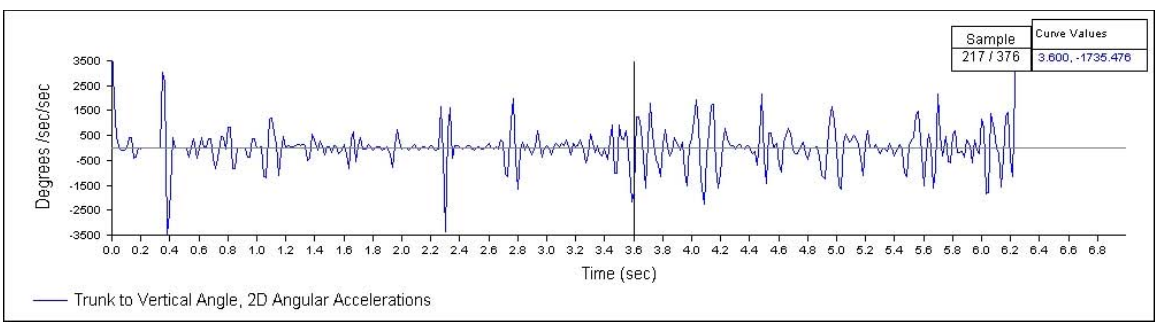


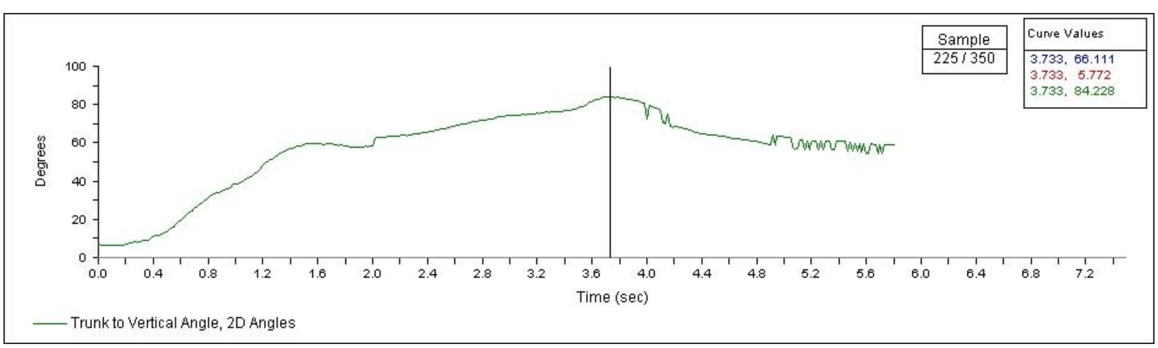
Table 9. Summary statistics for Head loading bottom litter (deg/sec and deg/sec^2)

	Trunk Velocity	Trunk Acceleration
Minimum	-56.57	-3469.66
Maximum	101.45	7911.94
Average	-0.01	41.73
Standard deviation	16.89	881.83

The Head 2 team member of Team Alpha also assumed trunk postures that exceeded 45 degrees while loading the litter on the bottom frame (see Figures 25 and 26).

Figure 25. Head 2 loading bottom litter

Figure 26. Head 2 peak trunk angle while loading bottom litter



One of the most extreme trunk postures observed for Team Bravo was when the participant at the Head stepped into the vehicle, placed the litter on the door of the vehicle, turned around and then proceeded to load the litter on the bottom frame (Figure 27). This maneuver is necessary because there is not another person available to hand-off the load.

Figure 27. Head preparing to load bottom litter

Eventhough the results were not able to quantitatively show data for the Foot member for most of Team Bravo, Figure 28 does show that trunk flexion did occur while performing this task simulation. It was observed that the participant assumed severe trunk flexion while loading the bottom and middle frames. By analyzing the video frames, the analyst assumes that the degree of trunk flexion during these tasks exceeded 45 degrees.

Figure 28. Foot loading bottom litter

8. **Task 4 Middle Litter Loading Postures**

Figure 29 clearly shows trunk flexion and shoulder extension while loading the middle frame. The participant held both handles while loading, requiring an extended reach across the frame, which then caused the lower back to bend forward.

Figure 29. Head 1 loading middle litter

Figure 30 illustrates similar lower back flexion and shoulder extension to the Head 1 individual of Team Alpha.

Figure 30. Head loading middle litter

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IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The postures observed in this study do expose crew members of the FCS MV-E to work-related musculoskeletal risks, particularly low back pain. The high risk postures were found especially while the subjects were loading litters on the bottom frame. Due to the design of the current study, using a 2-D software analysis package, and other limitations previously discussed, data are not available for each team member performing all tasks. Thus, inferential statistical analyses were not possible regarding the relative degree of posture severity of the 2-person and 3-person teams.

B. RECOMMENDATIONS

The current study served as a demonstration of a new approach to assessing ergonomic risk of manual material handling tasks. Below are several guidelines and suggestions regarding experimental design, methodology and approach to data analysis.

- First, a 3-dimensional motion capture software system is recommended. While analyzing a dynamic task such lifting and loading with more than one person involved, it is difficult to adequately capture all motions involved for each individual. The 2-D system restricted the use of trunk twisting motions, movement toward and from the camera, and motions that occur outside of the 2-D plane.
- When setting up cameras for data collection, ensure that the movements are captured in the entire camera field of view.
- Task events should be timed so that they are of approximately equal duration. However, the researcher must weigh that advantage against realistic simulation of the task as it is performed in an operational environment.

- When recruiting participants, use all combat medics with adequate experience performing litter casualty evacuations in the field. Also, experimental conditions should be as close as possible to the real environment. For example, medics should wear appropriate clothing and have gear and equipment such as helmet, body armor, and medical aid bag. This will enable human-system interface issues to be fully evaluated. Civilian participants may not perform the tasks as the medics would do in the field; the practice trials may not be adequate to learn coordination and hand-off skills that are necessary in loading litters in a team.
- A more detailed categorization of trunk postures is recommended. Instead of using two categories of trunk posture- severe or not severe- incorporate mild flexion and other categories according to the posture classification that specifically describe the level of severity.
- Analyze which tasks are performed better (i.e. less extreme postures) with a team size of two and which are better with a team size of three. For example, is loading the Sponson better with a 2-person team instead of a 3-person team, while loading the Bottom is better with a 3-person team?
- Suggested Research Question: Is there a difference in trunk postures for a 2-person team versus a 3-person team?
- Suggested Null Hypothesis: The distribution of severe trunk postures is the same for 2-person and 3-person teams.
- Suggested Alternate Hypothesis: The distribution of severe trunk postures for a 2-person team is different from the distribution for a 3-person team.
- In designing the experiment, allow participants to perform tasks in both a 2-person and 3-person team so that the performance of the

team member can be compared (a within-subjects design). Multiple replications of each task are recommended.

C. IMPLICATIONS FOR FUTURE RESEARCH

More research is needed that quantifies risk for upper extremities (to include shoulder, elbow, and wrist) and lower extremities other than the trunk. Total posture analysis of the body is needed while performing high-risk tasks. Predictive models have been developed as a way to project the degree of risk involved when performing a task. However, most predictive equations are based on lifting strength; minimal work has been done in developing predictive models based on posture. Also, further work is necessary in predicting risk of WMSDs by using trunk angular velocity and trunk angular acceleration. The review of literature found no accepted basis for establishing safe trunk velocity and acceleration while performing MMH tasks. Studies have used trunk velocity and trunk acceleration as factors to include in models, but an agreed hazardous range has not been identified. This study attempted to go beyond the traditional Revised NIOSH lifting equation to quantify lifting hazards and is also among the first to explore the area of posture analysis for MMH tasks involving teams. This study has demonstrated that use of a video motion capture system is an effective tool in the assessment of ergonomic risks of jobs such as MMH tasks. A video-based system is especially suitable for measuring human motion of team-oriented tasks. By using a video motion analysis system, joint segments of the body can be simultaneously recorded for operators performing different tasks. Another benefit of recording posture and body movement through a video-recording system is the analysis of trunk and upper extremity angular changes, velocities and accelerations. The work presented in this study impacts musculoskeletal injury prevention and prompts follow-on research applying these postural measurement techniques.

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APPENDIX A. GROUND AMBULANCE EVACUATION SUPPORT TASKS

Army soldiers in MOS 91 W are referred to as health care specialists. They are primarily responsible for providing emergency medical treatment, limited primary care and health protection and evacuation from a point of injury or illness. When Army physicians are not available, the health care specialist is authorized to provide basic and emergency medical treatment to injured or wounded soldiers (www.goarmy.com, retrieved November 2005). Although there is no civilian occupation that is directly equivalent to MOS 91W, emergency medical technicians and paramedics make use of the skills developed through MOS 91W training and experience. Some of the duties as a health care specialist include: taking patients' temperature, pulse and blood pressure; assisting with outpatient and inpatient care, administering emergency medical treatment to battlefield casualties; and recording patients' medical histories. This thesis focuses on the function of Medical Evacuation which is the systematic evacuation of sick, injured, or wounded soldiers. Medical evacuation encompasses – collecting the wounded for evacuation, sorting or triage, providing an evacuation mode, providing medical care, and anticipating complications and being ready and capable to perform emergency medical interventions (Army Field Manual 8-10-6, 2000). According Army Field Manual 8-10-6, en route care medical care has three major goals- (i) ensure patients are properly prepared by providing essential care prior to evacuation, (ii) ensure the medical evacuation system is able to transport/evacuate critically ill or injured patients on any available mode of transportation, and (iii) preserve or retain forward deployed medical personnel. Given the time-sensitive nature of treating critically injured soldiers and the need for an expedient field evacuation system, the FCS MV-E was designed. This vehicle allows health care specialists, maneuvering with combat forces, to be closer to the casualty's point-of-injury and is used for casualty evacuation. Table 10 below describes the individual steps medics are required to perform in the evacuation of casualty victims.

Table 10. Ground ambulance evacuation support tasks (After ARTEP 17-236-12-MTP)

TASK STEPS AND PERFORMANCE MEASURES
Note: If the platoon is equipped with FBCB2, it will be the primary means of communication unless otherwise specified by orders or the standing operating procedures (SOP). 1. Ambulance team prepares patients for evacuation. a. Triages patient(s) to determine priority of treatment. b. Evaluates patients. c. Consults the battalion aid station (BAS) for medical guidance, as required. d. Provides emergency treatment using established procedures. e. Places patient(s) on litters using procedures described in FM 8-10-6. f. Initiates/updates the field medical card (FMC) for each patient following procedures in AR 40-66 and FM 8-10-6. g. Employs safety procedures established in AR 385-10 and the TSOP. h. Employs environmental protection procedures established in AR 200-1 and the TSOP. 2. Ambulance team evacuates patients

a. Coordinates departure with supported unit headquarters.
b. Prepares ambulance to receive patients using procedures established in FM 8-10-6.
c. Loads the ambulance by loading litter patients and assisting the ambulatory patients using procedures described in FM 8-10-6.
d. Provides en route medical care.
e. Updates FMCs using procedures described in AR 40-66 and FM 8-10-6.
f. Unloads the ambulance by unloading ambulatory patients first, then litter patients using procedures described in FM 8-10-6.
g. Performs direct-exchange of medical equipment, as required.
h. Performs patient exchange with air or ground evacuation vehicles, as required.
i. Employs safety procedures using procedures described in AR 385-10 and the TSOP.
j. Employs environmental protection procedures outlined in AR 200-1 and the TSOP.

3. Ambulance team evacuates nuclear, biological, and chemical (NBC) contaminated patient(s).
   a. Prepares the ambulance to evacuate patient(s) using procedures described in FM 8-10-6.
   b. Verifies evacuation routes.
   c. Employs the appropriate MOPP level.
   d. Marks contaminated patient(s) IAW the the TSOP.
   e. Provides en route medical care.
   f. Notifies platoon headquarters that contaminated patient(s) is/are en route to their location.
   g. Unloads patient(s) at designated decontamination or treatment area using procedures described in FM 8-10-6.
   h. Decontaminates the vehicle and equipment.
   i. Performs self-decontamination.
   j. Employs safety procedures using procedures described in AR 385-10 and the TSOP.
   k. Employs environmental protection procedures using procedures described in AR 200-1 and the TSOP.
4. Ambulance section prepares for continuation of evacuation support.
   a. Replenishes the medical equipment set (MES).
   b. Performs preventive maintenance checks and services (PMCS) on vehicles and equipment using applicable TM(s).

c. Provides a situation report (SITREP) to the platoon leader/platoon sergeant or section leader.

d. Reports status to platoon leader/platoon sergeant or section leader prior to departure.

e. Transports Class VIII supplies to combat medics.

5. Ambulance section evacuates enemy prisoner of war (EPW) patient(s).

a. Provides en route medical care, if required.

b. Evacuates EPW patient(s) IAW the provisions of the Geneva Conventions.

c. Requesting unit provides guards.

d. Reports potential intelligence information IAW the TSOP and FM 8-10-8.

6. Field medical assistant/platoon sergeant coordinates with supporting medical company to have ambulances prepositioned at the BAS.

a. Briefs mission to all drivers – analog or digital graphics.

b. Issues strip maps and overlays to drivers.

7. Ambulance teams operate with maneuver elements of supported units.

a. Position ambulance with supported unit.

b. Perform PMCS using applicable TM(s).

c. Maintain communications with medical platoon headquarters and supported maneuver unit headquarters.

d. Report any enemy action to maneuver unit headquarters.

e. Prepare ambulance to receive patients.

f. Load ambulance using procedures described in FM 8-10-6.

g. Unload ambulance using procedures described in FM 8-10-6.

h. Perform direct-exchange of medical equipment, as required.

i. Coordinate departure with unit headquarters.

j. Provide en route medical care.

k. If required, initiate an FMC for each patient using procedures described in AR 40-66 and FM 8-10-6.

l. Update the FMC for each patient using procedures described in AR 40-66 and FM 8-10-6.

m. Transport patients to the BAS.

n. Prepare for the next mission.

o. Transport Class VIII resupply.

p. Employ safety procedures described in AR385-10 and the TSOP.

q. Employ environmental protection procedures outlined in AR 200-1 and the TSOP.

8. Ambulance team transfers patients from ambulance to air ambulance.

APPENDIX B. PHYSICAL TASK ANALYSIS QUESTIONNAIRE

Evaluation of the Physical Tasks Performed by FCS Medical Evacuation (MedEvac) Vehicle Medics

QUESTIONNAIRE

Please respond to the following questions. This questionnaire is designed to evaluate the physical tasks that medics must perform and the workspace in which these tasks must be completed. Based on your experience, provide clear and concise answers to each item below. The information you provide will strictly be used for research purposes.

Participant #: Date:

Start Time: End Time:

Participant Information

Age (yrs):

MOS:

Rank:

Time in Military:

Time on Active Duty:

Time since Last Deployment:

Dominant Hand:

Indicate the types of Army vehicles you have experience with and number of years/months in each:

Vehicle Name	# of Years
❒ M113 (2 man crew)	
❒ Stryker	
❒ Bradley (1 medic, 6-7 soldiers)	
❒ Hummv ❒ 996 ❒ 997 ❒ 998	
❒ Dusenhalf	
❒ LMTV (2 man crew)	
❒ M577 (4-5 man crew)	
❒ Other – FLA (2 man crew)	

The goals of this questionnaire include:

- To identify the tasks contents performed by MedEvac crew
- To identify the frequency and duration of performing these tasks
- To identify problems areas relating to medics' physical tasks
- To determine the tasks that are most physically demanding as indicated by SMEs
- To identify the task element(s) that make each task physically demanding
- To determine human task performance- performance time & error rate
- To determine which tasks are to be simulated

Area of focus: Physical tasks performed by medical crew

Scenario: Mission: Medical Evacuation Support for Combat Forces in the Offense or Defense. There are 3 Litter Casualties and 1 Ambulatory Casualty. Recover wounded soldiers for transport to Battalion Aid Station.
Condition: Medics will load wounded soldier on to litter/sked 4- man litter carry
Task: Load wounded soldier onto litter or sked and carry to medical evacuation vehicle on flat terrain.
Equipment: Full Combat Load

Part 1. Medics' Tasks and Physical Workload

1. Rate the following tasks (see attached list)

Task:____ **Task Number:** ___ ___ ___ ___

FREQUENCY
How often is this task performed. Once every ____? (**CHECK ONE**):

1 min A	5 min B	10 min C	30 min D	1 hour E	2 hours F	Few hours G
○	○	○	○	○	○	○

DURATION
How long does it normally take to perform this task? (**CHECK ONE**):

Less than 1 min A	1 min – 5 min B	6 – 10 min C	11 – 15 min D	16 – 30 min E	31 – 1 hour F	More than 1 hour G
○	○	○	○	○	○	○

PHYSICAL EXERTION
How would you describe the physical effort required for this task? (**CHECK ONE**):

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
No exertion at all	Extremely light		Very light		Light		Somewhat hard		Hard		Very hard		Extremely hard	Maximal exertion
○	○	○	○	○	○	○	○	○	○	○	○	○	○	○

Rate the task on all of these factors using this 1 – 7 scale.

extremely low	low	somewhat low	moderate	somewhat high	high	extremely high
1	2	3	4	5	6	7

Factors:

Muscular strength	Explosive strength	Muscular endurance	Flexibility	Coordination	Balance	Safety concerns	Mission criticality	Overall difficulty

2. At what point of continual work do you feel that the physical workload hinders optimal performance? (Give a range of time)

3. How often do the medics actually carry litters?
   - ❒ All of the time
   - ❒ Majority of the time (~ 60 – 75%)
   - ❒ Half of the time (50%)
   - ❒ Rarely
   - ❒ Never

4. From casualty pickup point to where the vehicle is stopped, what is the typical litter lift distance?

   Shortest Distance:

   Furthest Distance:

5. What is the shortest amount of time that you were actively taking care of a patient?

6. What is the longest amount of time that you were actively taking care of a patient?

7. In regards to the physical tasks, what are the common errors made by medics?

    What are the source(s) of those errors?

Part 2. Medic Training

8. How often do you perform a litter lift as you were trained?
    - ❒ All of the time
    - ❒ A little more than half of the time
    - ❒ Half of the time
    - ❒ Less than half of the time
    - ❒ Never

9. Think about the physical tasks you must perform-

    What area of your training do you feel you're most proficient in the field?

    What area of your training do you feel you're least proficient in the field?

Part 3. Medics' Equipment

10. What is the most gear worn while carrying a litter? (List items)

11. What is the most gear worn while taking care of patients in the back of the vehicle? (List items)

12. From the Medical Equipment Set (MES) list, what items are taken to the casualty point (not including the litter)?

13. What are other critical equipment?

Part 4. Medical Evacuation Vehicle & Interior Design

14. Describe the environmental conditions inside the vehicle. (Rate on Scale from 1 to 7; 1 = most comfortable to perform tasks, 7 = least comfortable to perform tasks)

- ❒ Temperature
- ❒ Ventilation
- ❒ Lighting
- ❒ Noise
- ❒ Vibration

15. Which design features of the vehicle allow for the most amount of physical stress for the medic crew?

16. Which design features of the vehicle allow for the least amount of physical stress for the medic crew?

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